# SOME SOIL FACTORS AFFECTING THE DISTRIBUTION OF BEECH IN A CENTRAL OHIO FOREST[1]

HAROLD C. FRITTS AND NICHOLAS HOLOWAYCHUK

*Department of Botany, Eastern Illinois University, Charleston, Illinois*
and
*Department of Agronomy, Ohio Agricultural Experiment Station, Columbus 10, Ohio*

## INTRODUCTION

A primary objective in plant ecology is understanding the relationships between the environment and the processes of the plant, and hence better understanding the development of its structure and form and its communal relationships. One approach to this problem lies in measuring the variations in some pertinent environmental factors and then evaluating their effects on the processes and structures of the plant.

During the summer of 1953 a study was conducted on radial growth of beech, *Fagus grandifolia* Ehrh., as related to soil moisture (Fritts, 1956a). A dial-gauge dendrometer was used to measure radial changes on three beech trees and these changes were related to soil moisture measurements in the three sites.

Each of the three trees had different regimes of radial growth which appeared to be associated with differences in soil moisture regimes. The tree on the best drained site had a gradual but early cessation of growth as soil moisture was reduced to wilting percent. The tree in the most poorly drained site had an even earlier cessation which was much more abrupt than that of the tree on the drier site. This cessation occurred at a time when the upper soil levels were drying rapidly. The tree in an area of intermediate drainage, with less competition from surrounding trees, had more available soil moisture for a longer period, and its growth continued later into the season.

The present study was undertaken to examine in detail these three soil environments grading from a moderately well-drained site, where the beech-maple association is dominant, to a very poorly drained site where beech is only an occasional associate of the swamp forest community. Other environmental and tree growth measurements were made concurrently (Fritts, 1956b) and these data are presented in a separate paper (Fritts, 1958).

## DESCRIPTION OF AREA

The forest in which this study was conducted, called Blacklick Woods, is a relatively undisturbed beech-maple and swamp forest tract located ten mi east of Columbus and one mi south-southwest of Reynoldsburg, Ohio (Fritts, 1956a). The area is on the gently undulating Wisconsin till plain, with elevations varying from 870 to 895 ft. A study area of 2.72 acres was selected to include one of the better drained sites in the forest as well as a poorly drained area where beech grows only along the edge of the depressions.

The soils of the area investigated have developed on moderately calcareous coarse clay loam or loam till and include three soil types, all members of the Alexandria Catena. Cardington silt loam, which is a moderately well-drained Gray-brown Podzolic soil, occurs on the low ridges and knolls. (The definitions of the soil drainage classes are defined in Soil Survey Manual [Soil Survey Staff, 1951].) Bennington silt loam, an imperfectly drained Gray-brown Podzolic soil,

[1]This paper is a contribution of the Department of Botany, Ohio State University, and the Department of Agronomy, Ohio Agricultural Experiment Station, State Project 106, Journal Paper No. 30-59. The study was done by the senior author as one phase of the dissertation required for the Ph.D. degree in the Department of Botany, Ohio State University, in cooperation with the junior author, Professor of Agronomy, Ohio State University.

is on the lower very gentle slopes between the low ridges and the depressions. The third soil type, the Marengo silty clay loam, is a very poorly drained Humic gley soil of the depressions.

In the analyses of the vegetation within the area, which has a total range in elevation of six ft, every tree over one in. dbh was mapped as to its location and relative elevation of the site (Fritts, 1956b). The total area, the number, and the basal area of each species included in the lower two-foot, the middle two-foot, and the upper two-foot contour intervals were calculated and the data plotted (fig. 1).

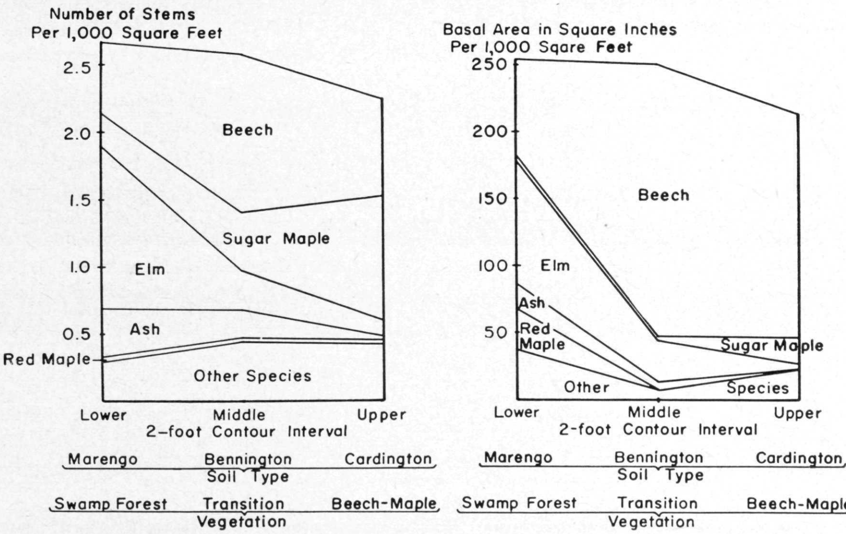



FIGURE 1. The numbers and basal area of stems over 1 in. dbh per 1,000 ft$^2$ on the three sites, as determined from mapping the trees and establishing 1-ft contour lines. Each soil type and its forest community was found, as indicated above, to lie within a 2-ft contour interval in the local study area. The relative proportion of each species is represented by proportionate areas for each site. The top line is equivalent to the total of all stems.

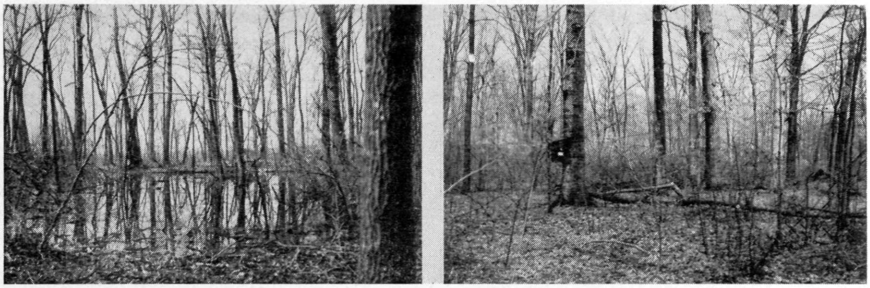


FIGURE 2. The early spring aspect of the swamp forest association on the Marengo silty clay loam (left) and the beech-sugar maple association on the Cardington silt loam (right).

Marengo silty clay loam is the prevalent soil in the lower two-foot interval. Bennington silt loam and Cardington silt loam are the dominant soils in the middle and upper two-foot intervals respectively. On the Marengo soil of the very poorly drained site, American elm (*Ulmus americana* L.), white ash (*Fraxinus americana* L.), and red maple (*Acer rubrum* L.) are the dominant species (fig. 2, left). Associated with them are: *Quercus bicolor* Willd, *Carpinus caroliniana* Walt, *Carya cordiformis* (Wang.) L. Koch, and *Tilia americana* L. Beech becomes established near the borders where the drainage is slightly better, but it is less important than elm. On the somewhat better drained Bennington soils, beech reaches its best development, small sugar maple trees (*Acer saccharum* Marsh.) become more abundant and elm becomes less important. In the more open areas of this site, the understory of spicebush (*Lindera benzoin* (L.) Blume) is more dense than anywhere else in the study area. Where better drainage prevails, as in the Cardington soil of the low knolls and ridges, beech and sugar maple are the dominant species (fig. 2, right). Also occurring on these better drained sites are *Celtis occidentalis* L., *Prunus Serotina* Ehrh., *Cornus florida* L., and *Asimina triloba* (L.) Dunal.

## METHODS

A detailed profile description of each of the soil types was made in a pit excavated within approximately ten ft of beech trees. The soil colors were determined in the moist state; the color terminology and Munsell notations used follow the definitions given in the Soil Survey Manual (Soil Survey Staff, 1951).

A bulk sample was taken of each of the soil horizons in each pit for laboratory analyses which included mechanical analyses and the determination of organic matter, pH, exchange acidity, and exchangeable calcium, magnesium, and potassium. The pipette method of Steele and Bradfield (1934) was used in the mechanical analyses with sodium hexametaphosphate as a dispersing agent. Organic matter and pH were determined by the method of Peech et al. (1947). Exchangeable calcium, magnesium and potassium were extracted with neutral normal ammonium acetate (Peech et al., 1947) and the extract analyzed on a Beckman Model DU flame photometer. Exchange acidity was determined with the method of Mehlich (1945), using a barium chloride solution buffered with triethanolamine.

Eight core samples were also taken when possible from each horizon at the three sites. Considerable difficulty was encountered in taking core samples of the C horizons of the Cardington and Bennington soils because of the appreciable content of rock fragments. On six of these core samples the following physical measurements were made: (1) bulk density and (2) the content of moisture expressed on volume basis at (a) saturation, (b) ten cm tension, (c) 60 cm tension, (d) one-third atm pressure, and (e) 15 atm pressure. The values obtained through these measurements were used to calculate total porosity, aeration porosity, and the available moisture as shown below:

$$\text{Bulk density} = \frac{\text{Weight of soil (oven dried) in gm}}{\text{Volume of soil in cm}^3}$$

$$\text{Total porosity} = \frac{\text{Moisture content in soil at saturation}}{\text{Volume of soil}}$$

$$\text{Aeration porosity} = \frac{\text{Moisture content at saturation} - \text{moisture content at 60 cm tension}}{\text{Volume of soil}}$$

$$\text{Available moisture} = \frac{\text{Moisture content at } \tfrac{1}{3} \text{ atm pressure} - \text{moisture content at 15 atm pressure}}{\text{Volume of soil}}$$

Wilting percent was determined on the remaining two core samples of each horizon by the following method: Oats were planted immediately after sampling and the samples were left in a controlled temperature and light room until the plants were four in. high, when watering was discontinued. When the majority of the plants became permanently wilted, i.e., would not regain turgidity when placed in a nearly saturated atmosphere overnight, the soil was weighed, oven-dried, and percent volume moisture was ascertained.

The tree root distribution was mapped in the field for a one-ft wide section of each of the three soil profiles (fig. 3). The Cardington root distribution was mapped in June, 1954; Bennington in August, 1955; Marengo in August, 1954.

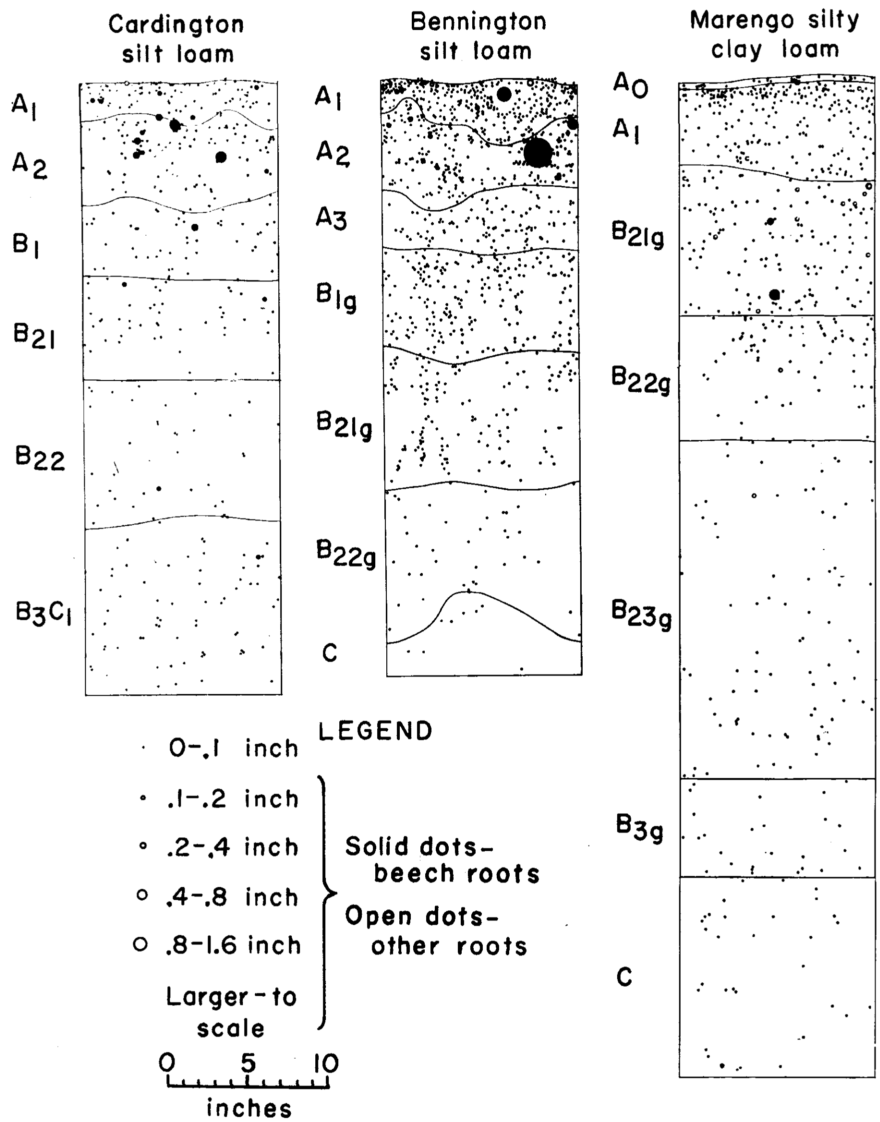



FIGURE 3. Map showing root size and distribution along a 1-ft transverse section of each soil profile. Beech roots greater than 0.1 in. diameter are indicated by solid dots and those of other species are indicated by open dots. Boundaries of the several soil horizons are indicated.

The density of all roots for each horizon was ascertained from the mapped section. In addition, all roots larger than 0.1 in. in diameter were identified and mapped as beech or nonbeech. This provided a means of estimating the extent of the more permanent root system of beech.

Field measurements of soil moisture were made by means of fiberglas-gypsum blocks (Youker and Dreibelbis, 1951). Six units were placed at each of the three depths—six, 12, and 24 in.—in undisturbed soil near the beech trees on each soil type. Resistance readings were made at intervals throughout the growing seasons of 1954 and 1955 by means of a Colman soil moisture meter. For calibration purposes, soil moisture samples were also taken at each of the three depths with a King-tube sampler near each unit at various times during the season and the moisture content was determined gravimetrically. This method for measuring soil moisture is discussed in the Southern Forest Experiment Station Occasional Papers (1953, 1954) and is described in more detail by Fritts (1956b).

Soil temperatures were measured at six, 12, 24, and 36-in. depths in each soil type by means of homemade thermistors and read with the Colman meter.

## RESULTS

### *Morphology of Soils*

The characteristics of each of the three soils as observed in the field are reviewed in the detailed descriptions and in the discussion following.

1. *Cardington silt loam.*—This soil was described and sampled in a pit located between two canopy beech trees on a 3 percent slope of a gently sloping knoll.

| *Depth and Horizon* | *Soil Profile Description* |
|---|---|
| 2–0″ $A_0$ | Leaf litter. |
| 0–2½″ $A_1$ | Very dark gray silt loam (10YR3/1 4/1); moderately developed, medium and coarse, granular structure. |
| 2½–7″ $A_2$ | Light yellowish brown coarse silty clay loam (10YR6/4); very weakly developed, subangular blocky to almost massive structure. |
| 7–12″ $B_1$ | Yellowish brown silty clay loam (10YR5/6), faintly mottled with light yellowish brown (10YR6/4), moderately developed, fine and medium, subangular structure; occasional sandstone pebbles present. |
| 12–18″ $B_{21}$ | Yellowish brown clay (10YR5/8), with prominent, large, brownish yellow (10YR6/8) and light brownish gray (10YR6/2) mottling; structure consists of moderately developed, fine prismatic forms that break up into strong, medium, subangular blocky units; some pebbles of shale, sandstone, and chert present. |
| 18–27″ $B_{22}$ | Yellowish brown clay (10YR5/6), with prominent, grayish brown mottling (10YR5/2 4/2); moderately developed, medium, angular and subangular blocky structure; pebbles of leached limestone and of black shale fragments common. |
| 27–38″ $C_1$ | Yellowish brown calcareous clay loam (10YR5/4), faintly mottled with brownish yellow (10YR6/6) and intermingled with prominent light brownish gray splotches and coatings of calcareous material (10YR6/2); weakly developed, coarse, prismatic structure; firm; numerous fragments of limestone and black shale present. |
| 38–54″ $C_2$ | Yellowish brown coarse clay loam till (10YR5/4 5/6), with few faint brownish yellow mottles (10YR6/6) and light brownish gray (10YR6/2) calcareous coatings; firm. Numerous pebbles and fragments of limestone and black shale present. |

2. *Bennington silt loam.*—The pit where this soil was sampled and described is located eleven and one-half ft from a beech tree, on a footslope occupying an

intermediate position between the knoll where Cardington silt loam was sampled and the shallow depressed area of Marengo silty clay loam soil. This footslope had a gradient of between one and two percent.

| *Depth and Horizon* | *Soil Profile Description* |
|---|---|
| 1–0″ $A_0$ | Partially decomposed leaf litter. |
| 0–2″ $A_1$ | Very dark gray silt loam (10YR3/1 4/1); moderately developed very coarse granular structure. |
| 2–6″ $A_2$ | Light brownish gray silt loam (2.5Y6/2); weakly to moderately very fine subangular structure. |
| 6–10″ $A_3$ | Gray coarse silty clay loam (10YR6/1) with common medium distinct yellowish brown mottles (10YR5/6); moderately developed fine subangular blocky structure. |
| 10–16″ $B_{1g}$ | Light brownish gray silty clay (2.5Y6/2) with many medium distinct yellowish brown mottles. The light brownish gray color more prominent on the structural unit surfaces; moderately developed fine subangular blocky structure. |
| 16–24″ $B_{21g}$ | Silty clay. Gray clayey coatings (2.5Y5/ ) with the interiors distinctly mottled with an intermingling of gray (2.5Y5/ ) and yellowish brown (10YR5/8); weakly developed medium prismatic structure breaking up into moderately developed angular and subangular blocky units. |
| 24–30″ $B_{22g}$ | Silty clay. Distinctly mottled color with an intermingling of yellowish brown (10YR5/8) and gray (10YR5/1) and (2.5Y5/ ); weakly developed coarse prismatic structure breaking up into weakly developed fine angular and subangular blocky units; some clayey coatings along structural unit surfaces. |
| 30–44″ $C_1$ | Brown calcareous clay loam till (10YR5/3 4/2) with gray coating (2.5Y6/ ) on prism faces and some yellowish brown mottling (10YR5/8); coarse weakly developed prismatic structure; very firm in place. Fragments of limestone black shale and yellowish brown limestone constitute about 20 percent of volume. |
| 44–56″ $C_2$ | Dark brown calcareous coarse clay loam (10YR4/3) with occasional gray coatings (2.5Y6/ ) along vertical faces; massive with some vertical partings; very firm in place. Fragments of limestone, sandstone and black shale and some igneous pebbles make up 15 to 30 percent of volume. |
| 56–63″ $C_3$ | Dark brown calcareous loam (10YR4/3) with rock fragments similar to those of $C_2$. Firm in place. |

3. *Marengo silty clay loam.*—This soil occupies a shallow depression about 75 yd wide. The site sampled and described is located near the edge of this depression and nine ft from a beech tree.

| *Depth and Horizon* | *Soil Profile Description* |
|---|---|
| 0–7″ $A_1$ | Very dark gray silty clay loam (10YR3/1); strongly developed fine and medium granular structure. |
| 7–15″ $B_{21g}$ | Gray clay (2.5Y5/ ) with fine faint brownish yellow mottling (10YR 6/6); moderately to strongly developed fine and medium angular blocky structure. |

| | |
|---|---|
| 15–22″ $B_{22g}$ | Clay, distinctly mottled with an intermingling of gray (2.5Y6/ ) and olive yellow (2.5Y6/8), with the gray occurring mainly on the structural unit surfaces; weakly to moderately developed fine angular blocky structure; some small soft black concretions present. |
| 22–42″ $B_{23g}$ | Clay, prominently mottled with an intermingling of brownish yellow (10YR6/8), light brownish gray (10YR6/2) and gray (5Y5/1); the gray colors mainly on structural unit surfaces; structure consists of weakly developed prismatic forms that break up into weakly to moderately developed medium size angular blocky units. |
| 42–48″ $B_{3g}$ | Silty clay loam mottled with an intermingling of brownish yellow (10YR6/8) and light gray (2.5Y10YR6/1) with the latter being more common on the structural unit surfaces; weakly developed medium prismatic structure breaking up into weakly developed subangular units. |
| 48–72″ $C_1$ | Yellowish brown calcareous coarse clay loam (10YR5/4) distinctly mottled with gray (10YR5/1) on the structural unit surfaces. Weakly developed fine subangular blocky structure. |
| 72–78″ $C_2$ | Pale brown calcareous coarse clay loam till (10YR2.5Y6/3) faintly mottled with grayish brown (10YR5/2). |

It is evident from the preceding descriptions that the three soils differ appreciably in colors of the various horizons. The yellowish brown hues are much more prevalent in the upper part of the profile of the Cardington soil. This is indicative of relatively better aeration. Gray colors, or the intermingling (mottling) of gray, yellow, and yellowish brown colors, are associated more with reduced aeration conditions such as are obtained when the soils are saturated for appreciable periods of time during the warmer season. The latter colors are more common throughout the subsoils in the Bennington and are especially extensive and well developed in the Marengo soil.

A characteristic distribution of structure may be noted in these soils. The A horizons in all three of the soils have a moderately to strongly developed granular structure. It is fine or very fine weakly developed subangular blocky in the $A_2$ horizons of the Cardington and Bennington soils, merging into coarser and strongly or moderately developed subangular or angular blocky in the B horizons. This better developed structure extends to a greater depth in the Cardington soil. In the case of the Marengo, a soil which lacks the $A_2$ or $A_3$ horizons, the granular and thicker A is underlain by horizons having more angular structure, though the units are generally fine or very fine and tend to be weakly developed. In general the angular or subangular units in the B horizons of the three soils tend to be arranged in weakly developed prismatic forms, the latter breaking up easily into the subangular or angular units mentioned. There is an increase in size and a decrease in degree of development of the structural units with depths, so that in the C horizons the structure is weakly developed coarse prismatic or massive. Also, the C horizons are rather dense and very firm, suggesting a lower degree of permeability to air and water, as well as to root penetration (fig. 3).

### *Chemical Properties*

The data obtained on the chemical properties of the soils are shown in table 1. It is evident that, outside of the $A_1$, the upper horizons of the Cardington and Bennington soils are very strongly acid with base saturation as low as 19 and 16 percent, respectively, in the $A_2$ horizons. There is a decrease in acidity and an increase in base saturation in these soils with depth in the lower B horizons, the profiles becoming calcareous in the C. Marengo silty clay loam is medium or strongly acid in the upper horizons only. The base saturation, with the lowest value being 49 percent, is appreciably higher in the upper part of the profile than in the other two soils.

Except for the $B_{1g}$ and $B_{21g}$ of the Bennington, calcium is the predominant exchangeable basic cation in the three soils, followed by magnesium and then potassium. The quantities of exchangeable bases in these soils differ appreciably, being relatively low in Cardington and Bennington in comparison to values obtained for the Marengo.

TABLE 1

*Chemical properties of Cardington, Bennington, and Marengo Soils in the study area, Blacklick Woods*

| Horizon | Depth (in in.) | Organic matter % | Nitrogen % | pH | Base saturation % | Exchange acidity ME/100gm | Exchangeable bases ME/100gm Ca | Mg | K |
|---|---|---|---|---|---|---|---|---|---|
| | | | Cardington silt loam | | | | | | |
| $A_1$ | 0 - 2½ | 7.3 | .32 | 5.5 | 51 | 10.2 | 8.6 | 1.6 | .36 |
| $A_2$ | 2½- 7 | 1.9 | .10 | 4.5 | 19 | 10.2 | 2.0 | .3 | .14 |
| $B_1$ | 7 -12 | 1.0 | .08 | 4.7 | 31 | 11.8 | 3.5 | 1.7 | .18 |
| $B_{21}$ | 12 -18 | .9 | .07 | 4.8 | 47 | 12.2 | 6.0 | 4.3 | .29 |
| $B_{22}$ | 18 -27 | 1.2 | .09 | 7.3 | 90 | 2.2 | 13.0 | 7.1 | .26 |
| $B_3C_1$ | 27 + | | | calcareous | | | | | |
| | | | Bennington silt loam | | | | | | |
| $A_1$ | 0 - 2 | 5.7 | .33 | 5.8 | 44 | 13.2 | 8.0 | 2.1 | .40 |
| $A_2$ | 2 - 6 | 1.7 | .11 | 5.2 | 16 | 11.1 | 1.3 | .6 | .16 |
| $A_3$ | 6 -10 | .4 | .05 | 4.9 | 17 | 11.7 | 1.1 | 1.2 | .10 |
| $B_{1g}$ | 10 -16 | .6 | .06 | 5.0 | 33 | 14.8 | 3.3 | 3.7 | .19 |
| $B_{21g}$ | 16 -24 | .6 | .07 | 5.1 | 50 | 12.2 | 5.8 | 6.2 | .26 |
| $B_{22g}$ | 24 -30 | .8 | .07 | 6.2 | 83 | 4.0 | 10.8 | 8.3 | .26 |
| C | 30 + | | | calcareous | | | | | |
| | | | Marengo silty clay loam | | | | | | |
| $A_1$ | 0 - 7 | 8.3 | .41 | 5.3 | 49 | 16.6 | 11.5 | 3.8 | .53 |
| $B_{21g}$ | 7 -15 | 1.3 | — | 5.0 | 57 | 10.7 | 9.3 | 4.5 | .29 |
| $B_{22g}$ | 15 -22 | 0.9 | .06 | 5.3 | 70 | 6.8 | 10.0 | 5.5 | .28 |
| $B_{23g}$ | 22 -42 | 0.9 | — | 6.0 | 78 | 4.7 | 10.0 | 6.2 | .25 |
| $B_{3g}$ | 42 -48 | 1.4 | .07 | 6.8 | 87 | 2.4 | 10.5 | 5.7 | .18 |
| C | 48 + | | | calcareous | | | | | |

There are some differences in the distribution and content of organic matter in the three profiles. Both the Cardington and the Bennington soils have a surface layer (A horizon) about two in. thick with a relatively high organic matter content—7.3 and 5.7 percent, respectively. There is a sharp decrease in these values in the underlying horizons. In the case of the Marengo soil, the A horizon has an organic matter content of 8.3 percent and is seven in. thick. Thus, to a depth of about six or seven in., the Marengo soil contains appreciably more organic matter than do the other two soils.

The C horizons in these soils are calcareous. Though the data on the carbonate equivalent content have not been included in table 1, the values range between 13.3 to 23.0 percents. The depth of the calcareous C horizon is greater in the Marengo, being 48 in., while it is only 27 and 30 in., respectively, in the Cardington and Bennington soils.

### *Physical Properties*

A number of physical properties of these soils which may contribute to the local distribution of beech were measured at each horizon. Measured or derived values were obtained for mechanical composition, bulk density, total and aeration porosity, moisture retention capacities at different degrees of extraction, and wilting percent. In addition, the seasonal changes in soil temperature and moisture content at various depths were determined, and an analysis of root concentration was made from the maps of each profile. Results are presented in tables 2, 3, and 4, and in figures 4 through 8. Each of the physical properties is considered separately in the following discussion.

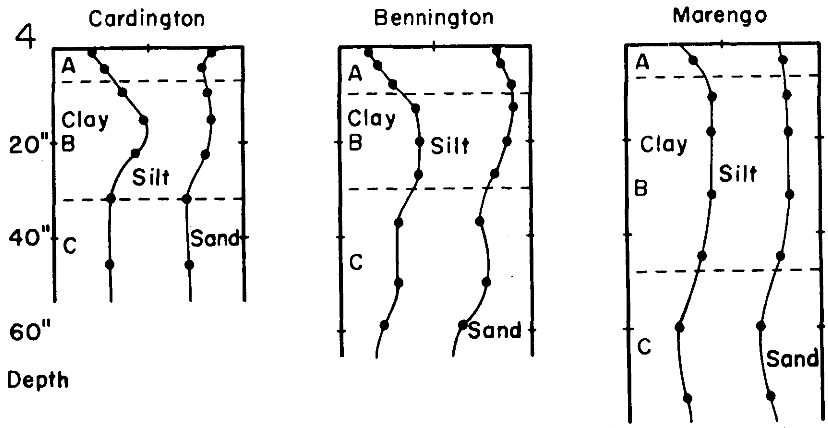
TABLE 2

*Root distribution and some physical properties of Cardington, Bennington, and Marengo soils in the study area, Blacklick Woods*

| Horizon | Depth (in in.) | Sand % | Silt % | Clay <0.002 mm diameter % | Bulk density | Total porosity % | Aeration porosity % | "Available" water, in. water per in. of soil | Roots per in$^2$. |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Cardington silt loam | | | | | |
| $A_1$ | 0 - 2½ | 16.9 | 62.3 | 20.8 | — | — | — | — | 3.74 |
| $A_2$ | 2½ - 7 | 20.4 | 51.4 | 28.2 | 1.34 | 55 | 18.9 | .237 | 1.69 |
| $B_1$ | 7 -12 | 17.9 | 45.7 | 36.4 | 1.52 | 45 | 12.3 | .117 | .94 |
| $B_{21}$ | 12 -18 | 15.7 | 36.1 | 48.2 | 1.52 | 48 | 8.5 | .123 | .67 |
| $B_{22}$ | 18 -27 | 19.8 | 36.4 | 43.8 | 1.61 | 42 | 7.1 | — | .35 |
| $B_3C_1$ | 27 -38 | 29.8 | 40.3 | 29.9 | — | — | — | — | .55 |
| $C_2$ | 38 -54 | 29.0 | 41.7 | 29.3 | — | — | — | — | — |
| | | | | Bennington silt loam | | | | | |
| $A_1$ | 0 - 2 | 17.6 | 66.6 | 15.8 | — | — | — | — | 9.32 |
| $A_2$ | 2 - 6 | 15.6 | 64.2 | 20.2 | 1.33 | 46 | 11.7 | .125 | 4.77 |
| $A_3$ | 6 -10 | 10.0 | 61.3 | 28.7 | 1.44 | 44 | 11.8 | — | 2.57 |
| $B_{1g}$ | 10 -16 | 8.7 | 51.1 | 40.2 | 1.39 | 46 | 9.1 | .134 | 2.79 |
| $B_{21g}$ | 16 -24 | 11.8 | 45.9 | 42.3 | 1.47 | 45 | 5.3 | .083 | 1.39 |
| $B_{22g}$ | 24 -30 | 18.3 | 40.3 | 41.4 | 1.55 | 42 | 4.7 | .080 | .40 |
| $C_1$ | 30 -44 | 26.2 | 42.5 | 31.3 | — | — | — | — | .21 |
| $C_2$ | 44 -56 | 23.7 | 45.7 | 30.6 | — | — | — | — | — |
| $C_3$ | 56 -63 | 36.8 | 40.4 | 22.8 | — | — | — | — | — |
| | | | | Marengo silty clay loam | | | | | |
| $A_1$ | 0 - 7 | 18.2 | 46.4 | 35.4 | 1.13 | 58 | 10.9 | .250 | 3.58 |
| $B_{21g}$ | 7 -15 | 15.7 | 39.0 | 45.3 | 1.40 | 47 | 6.5 | .145 | 1.41 |
| $B_{22g}$ | 15 -22 | 15.3 | 40.5 | 44.2 | 1.53 | 43 | 5.0 | .114 | .80 |
| $B_{23g}$ | 22 -42 | 15.4 | 40.0 | 44.6 | 1.58 | 42 | 5.2 | .096 | .34 |
| $B_{3g}$ | 42 -48 | 20.0 | 40.9 | 39.1 | — | — | — | — | .36 |
| $C_1$ | 48 -72 | 31.5 | 41.5 | 27.0 | 1.72 | 37 | 3.4 | .064 | .23 |
| $C_2$ | 72 -78 | 26.5 | 43.4 | 30.1 | — | — | — | — | — |

1. *Mechanical composition* (*soil texture*).—The percents of sand, silt, and clay in each horizon are included in table 2 and their relative distribution with depth is shown in figure 4. It is evident that both the Cardington and Bennington are characterized by a comparatively low clay content in the A horizons, having minimum values of 20.8 and 15.8 percent, respectively. There is a pronounced increase in this fraction in the B horizons of these two soils, with maximum values

being 48.2 and 42.3 percent. This contrast in clay content of the A and the B is less marked in the Marengo, though there is some increase in this fraction in the B horizon. A value of 35.4 percent was obtained for the $A_1$ while a maximum content of 45.3 percent was found in the $B_{21g}$. The clay content is fairly uniform in the C horizons, which constitute the till parent material of these soils. Values obtained range from 22.8 to 31.3 percent, but most of these samples contain around 30 percent clay.



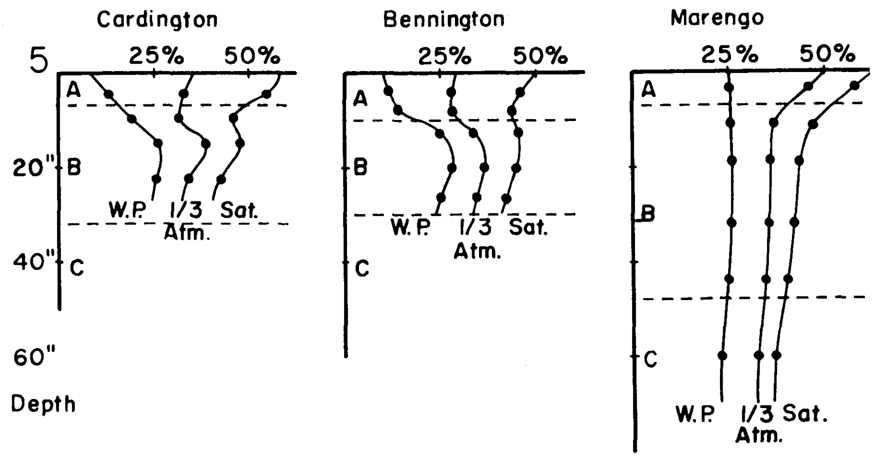




FIGURE 4 (top). The relative proportions of sand, silt, and clay in the profiles of the Cardington, Bennington, and Marengo soils. The area between lines at a given depth represents the percent of each soil fraction. A, B, and C are the three master soil horizons.

FIGURE 5 (bottom). Distribution of percent volume of moisture retained at saturation, at one-third atm, and at wilting percent at various depths in the profiles of Cardington, Bennington, and Marengo soils. A, B, and C are the three master soil horizons.

One of the soils, the Bennington, shows a relatively higher content of the silt portion in the upper part of the profile. The silt content exceeds 60 percent in the $A_1$, $A_2$, and $A_3$ horizons, and 50 percent in the $B_1$ of this soil. This is appreciably higher than the values obtained for the Cardington soil at comparable depths.

2. *Bulk density*.—Data in table 2 indicate that the bulk densities are relatively low in the $A_1$ horizons of the three soils, with values of around one or slightly

greater. They increase progressively with depth, reaching a value slightly above 1.5 in the $B_2$ horizons, and around 1.7 in the C. Only one measurement is available on the $A_1$ horizon—that of the Marengo, for which an average value of 1.13 for six core samples was obtained. Core samples of this horizon in the Cardington and the Bennington soils were not taken because of the sampling difficulties encountered due to the shallowness of that horizon and the profusion of horizontal roots near the surface. The organic matter content of this horizon in these two soils is nearly as high as that of the Marengo, and hence it is estimated that their bulk densities would have values comparable to that of the Marengo. No serious difficulties were encountered in the sampling of the B horizons of the three soils; so a larger number of measurements are available; but in the C horizons of the Cardington and Bennington, the presence of rock fragments precluded the taking of good samples. For this reason only one set of C horizon bulk density measurements was made, that of the Marengo, for which an average value of 1.72 was obtained. Judging from bulk density measurements made on the C horizons of other comparable soils in central Ohio, the above value can be accepted for the other two soils.

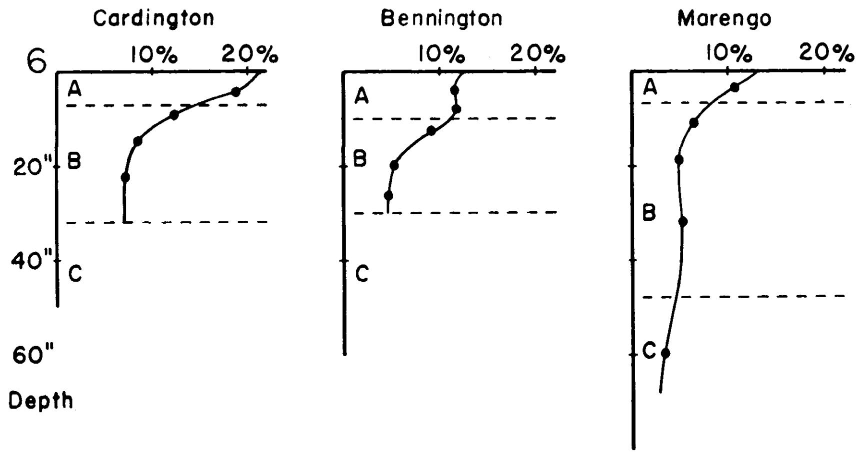
3. *Soil moisture retention capacities.*—The quantities of moisture retained by the three soils at various depths and at different degrees of extraction or saturation are shown in figure 5. Wilting percent, which was determined with the use of oat seedlings, shows the greatest variation with depth, especially in the Cardington and Bennington soils. The quantities of moisture retained by these two soils at wilting percent are respectively 12.7 and 14.0 percent of soil volume in the $A_2$ horizons, reaching maxima of 26.6 and 28.1 percent in the $B_2$. In this respect the wilting percent tends to parallel the content of clay at different depths in the profiles. A more uniform distribution with depth of wilting percent values may be noted in the Marengo soil. In this case, the moisture retained at wilting percent varies from 25.5 to 26.8 percent in the A and the B horizons. A lower value of 21.3 percent was obtained in the C.

The moisture retained by a soil after it has been wetted and then subjected to one-third atm of air pressure, is generally considered to be a measure of its capacity to hold moisture when saturated and allowed to drain under field conditions. The values obtained for this moisture retention capacity at various depths in the three soils are shown graphically in figure 5. In the A horizons of the Cardington and Bennington, the one-third atm moisture values are 32.5 and 27.7 percent soil volume and increase to maxima of 38.6 and 36.8 percent in the B horizons. In the case of the Marengo soil, this moisture value is 46.8 percent in the A, decreasing to 35.9 in the $B_2$, and to 32.5 percent in the C.

The difference between the quantity of moisture retained at 15 atm and one-third atm pressure is indicative of the quantity of moisture a soil can retain that can be used by the plant. It is referred to as "available" water, and in table 2 is expressed as the inches of available water that one in. of soil can hold. (The pressure membrane measurement of 15 atm is used here instead of wilting percent, since the former was made on the same cores as were used for one-third atm determination.) The upper horizons exhibit the largest capacities. Values of 0.237, 0.125, and 0.250 were obtained for the $A_1$ or $A_2$ horizons of Cardington, Bennington, and Marengo soils. These values decline with depth in the subsoils (with the exception of a slight increase in the$B_{1g}$ of the Bennington), the lowest value of 0.080 occurring in the $B_{22g}$ horizon of the Bennington. Even lower quantities apparently could be expected in the C horizons, since a value of only 0.064 was obtained at this depth in the Marengo soil. An additional means for expressing graphically the available water holding capacities of the three soils is provided in figure 5. The area between the wilting percent and the one-third atm curves is a measure of this capacity with depth in each soil.

Quantity of water retained by the soil when saturated was also measured.

Since saturation implies the filling of the larger pores with water, the increase in moisture content at saturation over the content at one-third atm will be dependent on the magnitude of aeration porosity. Examination of figure 5 reveals the highest saturation values in the A horizons where aeration porosity is greatest. Somewhat lower quantities were found in the B and the lowest in C.



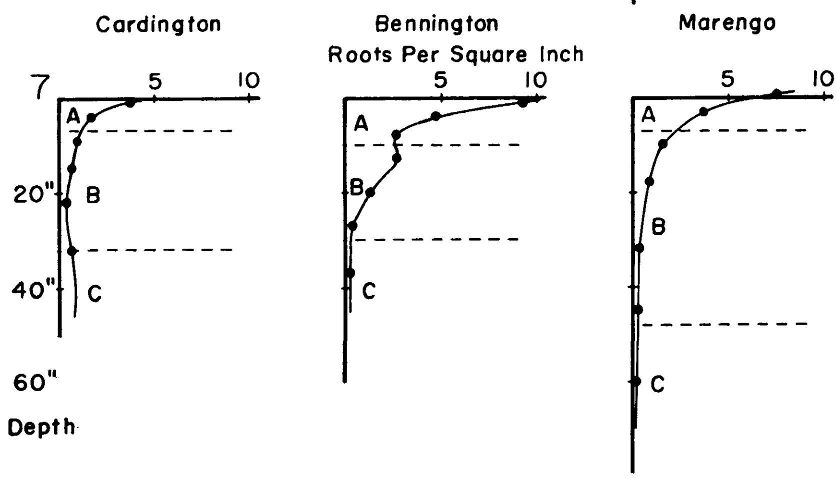




FIGURE 6 (top). Percent aeration porosity for each horizon in the Cardington, Bennington, and Marengo soils. A, B, and C are the three master horizons.

FIGURE 7 (bottom). Root density per horizon in the Cardington, Bennington, and Marengo soils. A, B, and C are the three master soil horizons.

4. *Total and aeration porosity.*—Total porosity (i.e., the percent by volume of the pore space in the soil) is inversely related to the bulk density. As shown in table 2, it is greatest in the A horizon and least in the C of the three soils investigated. A value of 58 percent was obtained for the $A_1$ horizon of the Marengo and comparable values could be expected in the $A_1$ horizon of the other two soils. A value of 37 percent was obtained for the C horizon of the Marengo, which is indicative of the decline in aeration porosity with increasing bulk density. The total porosity values of the B horizons of these soils are of intermediate magnitude, ranging from 42 to 48 percent.

There are more marked differences in relative extent of the aeration porosity at different depths in these soils. The values reported in table 2 and shown in figure 6 represent the percent by volume of the space occupied by the larger pores in the soil. These values are an index of the quantity of the larger pore spaces through which air and water may move more readily and hence may be especially significant in tree growth through the effect on growth and distribution of roots. The aeration porosity values are relatively high in the A horizons, ranging from 10.9 in the Marengo, up to 18.9 percent in the Cardington. They are considerably lower in the B horizons, especially in the $B_{22g}$ of the Bennington and the Marengo soils where values of 4.7 and 5.0 percent, respectively, were obtained. This decrease in aeration porosity in the subsoil is not as great in the Cardington soil,

TABLE 3

*Average monthly temperatures in degrees F, May through October of 1954 and 1955, at the 6, 12, 24 and 36-in. depths in Cardington, Bennington, and Marengo soils, Blacklick Woods*

| Depth | May | | June | | July | | August | | September | | October | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (in in.) | 1954 | 1955 | 1954 | 1955 | 1954 | 1955 | 1954 | 1955 | 1954 | 1955 | 1954 | 1955 |
| | | | | | Cardington silt loam | | | | | | | |
| 6 | 51.3 | 56.3 | 60.4 | 58.8 | 63.5 | 63.5 | 65.7 | 64.8 | 62.0 | — | 60.0 | — |
| 12 | 52.3 | 56.3 | 60.8 | 58.3 | 62.8 | 63.0 | 63.7 | 64.8 | 61.7 | — | 60.3 | — |
| 24 | 52.2 | 54.3 | 58.4 | 58.0 | 61.0 | 60.0 | 63.2 | 63.2 | 61.7 | — | 61.3 | — |
| 36 | 50.8 | 52.5 | 55.8 | 55.5 | 59.2 | 57.5 | 62.0 | 61.8 | 61.0 | — | 60.7 | — |
| | | | | | Bennington silt loam | | | | | | | |
| 6 | — | 57.0 | 62.2 | 60.3 | 64.5 | 63.3 | 65.7 | 64.8 | 61.3 | — | 58.7 | — |
| 12 | — | 56.0 | 61.0 | 58.8 | 64.3 | 62.8 | 65.8 | 64.8 | 62.7 | — | 60.0 | — |
| 24 | — | 53.8 | 59.4 | 56.0 | 62.3 | 59.5 | 64.2 | 62.8 | 61.7 | — | 59.3 | — |
| 36 | — | 52.8 | 56.4 | 55.0 | 60.3 | 57.8 | 61.2 | 61.8 | 61.3 | — | 60.7 | — |
| | | | | | Marengo silty clay loam | | | | | | | |
| 6 | — | 57.5 | — | 61.3 | 66.7 | 65.0 | 66.5 | 65.6 | 60.7 | — | 58.5 | — |
| 12 | — | 58.5 | — | 60.3 | 66.0 | 65.3 | 67.0 | 66.8 | 62.3 | — | 61.0 | — |
| 24 | — | 56.0 | — | 59.3 | 63.8 | 61.3 | 65.2 | 64.0 | 62.0 | — | 61.0 | — |
| 36 | — | 54.8 | — | 58.0 | 61.8 | 60.0 | 63.2 | 63.6 | 61.3 | — | 60.5 | — |

the values being 8.5 and 7.1 for the $B_{21}$ and the $B_{22}$ horizons. Very low values appear to be common to the C horizons, as indicated by the 3.4 percent obtained for this horizon in the Marengo soil. This strongly suggests a very low permeability to air and water in this part of the three profiles.

It should be pointed out that in the $A_2$ horizon of the Bennington the available water, as well as the total and aeration porosity, is markedly lower than in the $A_2$ of the Cardington and at comparable depths in the Marengo. Apparently the higher silt content of the Bennington has a pronounced effect on the water relations.

5. *Soil temperatures by seasons.*—Soil temperature data averaged by months for the measured portions of the years 1954 and 1955 are presented in table 3. In this forest during the spring and early season, the Marengo soils appear to be warmest and the Cardington coolest to a depth of at least 36 in. In the autumn, the Marengo cools most rapidly and the Cardington least rapidly. However, temperature differences among the three soils at the same depths and at the same time were seldom greater than 2 or 3°F.

6. *Root numbers and distribution.*—The average root densities per horizon shown in table 2 and in figure 7 indicate the effects of the several soil factors on root development. The better drained and aerated Cardington soil, in comparison with the Bennington, has a lower density of roots in the upper soil levels; but the root numbers as a whole do not decrease as markedly with depth in the B and C horizons. The lower root density in the Cardington may be due partly to the fact that the roots were mapped two months earlier in the season (June), and partly due to less available moisture in this soil during the greater part of the growing season. Below the B, the density of roots actually increases in the lighter textured C horizon. This is apparent not only in the number of roots but also in their increased size and branching. A tree in this type of soil, therefore, would be likely to have a deep root system.

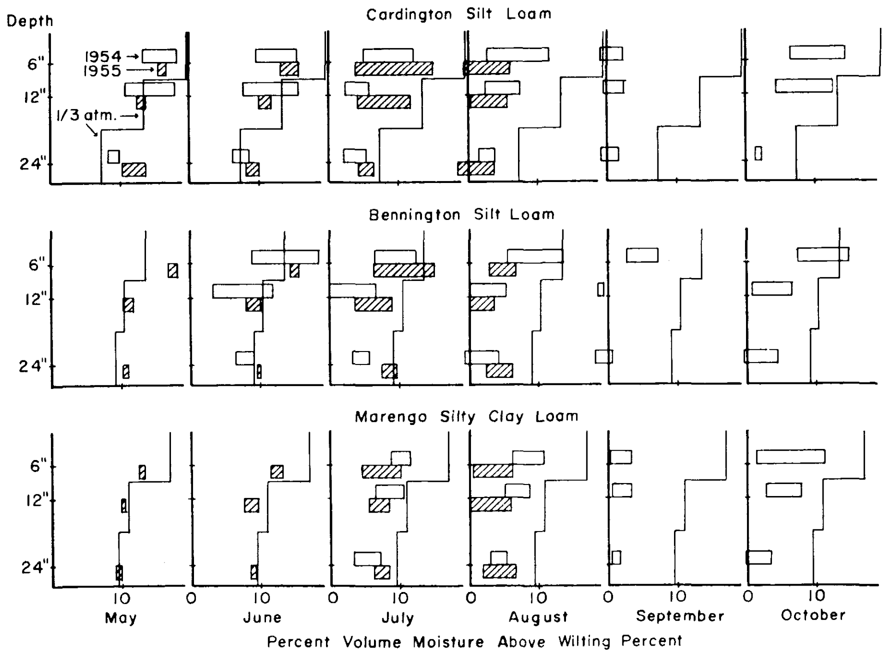



FIGURE 8. The observed monthly range of percent volume soil moisture above wilting percent at the six, 12, and 24-in. depths for the Cardington, Bennington, and Marengo soils during 1954 and 1955. The steplike line represents one-third atm tension minus wilting percent for each of the three depths.

In the Bennington soil there is a high concentration of roots in the $A_1$ horizon; they occur in appreciable numbers down into the $B_{1g}$ as well, but decrease sharply below this depth. The greater concentration of roots appears to be confined to the horizons having higher porosity values and a relatively high silt content. The roots evidently branch profusely in the $A_1$ and upper $B_{1g}$ where aeration is relatively favorable, but in the lower B horizon they become less and less extensive where the clay content becomes higher and aeration lower. Few roots appear to penetrate below this layer. A tree in this soil type would have a more concentrated root system, restricted largely to the A and upper B horizons.

The Marengo soil has an even more marked decrease in root numbers with depth. Here aeration drops off rapidly with depth, especially during the spring and early summer when the soil is saturated. As a consequence, the roots are largely restricted to the upper soil horizons.

An even more striking contrast of root penetration into these soils may be noted in the distribution patterns with depth of the larger roots (i.e., roots of 0.1 in. diameter or greater). From table 4 it is evident that these larger roots of beech are relatively extensive and deep in the Cardington; that they are restricted mostly to the A horizons in the Bennington; and that in the Marengo they are relatively shallow and less frequent.

TABLE 4

*Number of roots larger than 0.1 in. diameter of beech and of other species by horizons exposed in one ft transverse section in Cardington, Bennington, and Marengo soils, Blacklick Woods*

| Horizon | Depth (in in.) | Roots, diameter >0.1 in. Beech | Others |
|---|---|---|---|
| | Cardington silt loam | | |
| $A_1$ | 0 - 2½ | 5 | 1 |
| $A_2$ | 2½- 7 | 8 | 0 |
| $B_1$ | 7 -12 | 1 | 0 |
| $B_{21}$ | 12 -18 | 2 | 0 |
| $B_{22}$ | 18 -27 | 1 | 0 |
| $B_3C_1$ | 27 -38 | 1 | 0 |
| | Bennington silt loam | | |
| $A_1$ | 0 - 2 | 5 | 3 |
| $A_2$ | 2 - 6 | 5 | 0 |
| $A_3$ | 6 -10 | 0 | 0 |
| $B_{1g}$ | 10 -16 | 0 | 0 |
| $B_{21g}$ | 16 -24 | 0 | 0 |
| $B_{22g}$ | 24 -30 | 0 | 0 |
| C | 30 -44 | 0 | 0 |
| | Marengo silty clay loam | | |
| $A_1$ | 0 - 7 | 0 | 2 |
| $B_{21g}$ | 7 -15 | 2 | 10 |
| $B_{22g}$ | 15 -22 | 0 | 1 |
| $B_{23g}$ | 22 -42 | 0 | 1 |
| $B_{3g}$ | 42 -48 | 0 | 0 |
| C | 48 -72 | 0 | 0 |

7. *Seasonal soil moisture changes.*—Measurements of soil moisture content at the six, 12, and 24-in. depths were made periodically during the period of May through October in 1954 and 1955. A summary of the data obtained during these two years is presented graphically for each soil in a series of monthly charts in figure 8. Each monthly chart shows the observed range in fluctuations of soil moisture readings above the wilting percent value at each depth.

All the soils were wet (i.e., soil moisture content exceeded one-third atm values) during the early part of the season. Ponded conditions generally prevail on the Marengo soil. There may be some doubt about the moisture readings obtained for the Marengo soil during the month of May. At several times when measurements were being taken on this soil, there was a puddled condition which suggested that moisture content exceeded one-third atm values; yet this was not indicated by the resistance readings obtained on the moisture blocks. The error here is probably due to the lack of calibration points while the soil was in this ponded condition. Accurate samplings at this time could not be made.

The moisture in the A horizon of the Cardington first began to decrease in May, although a saturated layer remained above the clay maximum in the B horizon well into June. It is evident that during this time water entering the soil exceeded that which was removed by roots or by percolation. Therefore, considerable internal lateral movement must have occurred down the slope into the upper horizons of the lower soils, augmenting their saturated condition. This was evidenced by seepage from the sides of the holes or pits which were open at that time. In June, as transpiration and root growth increased, water was removed from the soil more rapidly and the moisture in all soils began to decline. During the rest of the season, soil moisture variations at the recorded depths were the resultant of the moisture changes through additions by rain, and removal by the roots. In the moderately well-drained Cardington soil, where the root concentration was less dense and the roots were more evenly distributed throughout the profile, the soil moisture was reduced proportionally at all depths. The greatest moisture changes occurred in the upper horizon, the fluctuations corresponding with the rainy and the rainless periods.

The Bennington soil had a marked contrast between the moisture regimes at the three depths. At the six-in. depth, the measured soil moisture was never reduced to wilting percent during the two years studied, while at the 12-in. depth soil moisture dropped earlier and more rapidly than in any other site at the equivalent depth. At the 24-in. depth the soil moisture regime was similar to that of equivalent depths in the other two soils.

Several factors may account for the contrast in the Bennington regime. Two soil moisture stations on the Bennington were located on the margin of an opening in the canopy made by a windthrow. The dense understory of spicebush, a partially decomposed stump, and the eccentric crowns of neighboring trees indicated that the open condition had existed for a number of years. Because of the opening, a large portion of rainfall reached the soil surface and high moisture levels were maintained in the A horizon. In addition, the total water-holding capacity (see available water, table 2) is lower in the A of the Bennington than in the corresponding horizons in the other two soils; with a rain, this lower water-holding capacity would result in a rapid percolation of water, since field capacity would be quickly reached. The opening in the canopy and the resulting higher rainfall reaching the soil at the two stations, and the more rapid percolation in the Bennington resulted in a more frequent replenishing of the soil moisture at the six-in. depth than occurred in the other soils.

However, even in the Bennington, moisture from summer rains seldom reached the 12-in. level. The moisture accumulated in this soil during the winter and spring is readily depleted by the high number of roots in the upper B horizon and wilting percent may first occur here as it did in July, 1954 (fig. 8). The tight $B_{22g}$ horizon prevents large numbers of roots from reaching the 24-in. depth and the moisture regime shows less variation.

In the poorly drained Marengo site the soil moisture regimes at both the six and 12-in. depths were more alike, and the moisture, while below field capacity, did not become very low until August or September. At the 24-in. depth, where roots were sparse, there was much less variation; wilting percent was not attained until still later in the season, when aeration was sufficient to allow deeper root penetration, thus causing greater water loss from this lower depth.

## DISCUSSION

It is apparent from these data that the soil environment changes appreciably in this forest throughout the range of beech. It appears to have a great influence upon the root distribution. The structural and aeration porosity differences in the soil profiles favor deeper root penetration in the Cardington, while the beech roots are more restricted to and concentrated in the shallower depths of the

Bennington, and are most restricted in the Marengo. These differences are due largely to the higher early-season moisture and poorer aeration in the more poorly drained sites.

In all three soils, the roots below the A horizons are largely confined to the outer surfaces of the soil structural units. In the high clay $B_2$ horizons, where the structural units become larger, there is less potential total area for root growth and consequently less root penetration. In the Cardington, although this $B_2$ horizon reaches a high maximum concentration of clay, it is not as deep; it has a higher aeration porosity, and the structure is somewhat more strongly developed than in the other two soil types. These conditions evidently allow the roots to penetrate the layer and reach the lighter textured C horizon where the roots increase in density and size. In the Bennington, fewer beech roots can penetrate the B horizon, and in the Marengo, where the areation of the B is even lower, still fewer beech roots occur.

In the Marengo, the high base status and the high organic content might be favorable to a high root growth in the $A_0$ and $A_1$, when, in mid and late summer, aeration is not limiting; but at times when the aeration is poor, the slightly higher temperatures may cause respiration of the roots to be somewhat greater and make aeration a more potent limiting factor.

Furthermore, a root system should be considered as a dynamic rather than a static system, where many of the deeper roots in poorly drained soils may die back to a greater or lesser extent in the spring, depending upon the soil conditions and the characteristics of that particular species. Absence of large beech roots in the Marengo soil seems to substantiate this. As the soils progressively dry and growing conditions become more favorable, the roots grow into lower areas of higher moisture content. During an average summer when temperatures are not extreme and transpiration is not excessive, the root systems of beech can extend with sufficient rapidity in all three sites to supply water for the entire growing season; but in a summer such as 1952 (Fritts, 1956a), when the soil moisture is high during early season but decreases rapidly during July when air temperatures are high, the root system of the beech on the Marengo soil may not grow rapidly enough into the moist layers to maintain sufficient water absorption. This would result in a water deficit in the tree with a consequent early and abrupt cessation of growth, coinciding with the beginning of hot, dry weather.

If the drought of 1952 had been even more severe, the beech trees in this poorly drained site may have died. Braun (1936) mentions such cases occurring on Illinoian till in southwestern Ohio. She says, ". . . the shallowness of the root systems of beech in wet and poorly aerated soil resulted in high mortality of this tree in depressions in the 1930 drought." Shanks (1942) also states that the root systems in the swamp forest of Trumbull County, Ohio, are very superficial and that in this swampy region the beeches frequently have dead tops.

It is very likely that an extremely wet spring and summer would also be unfavorable for growth of beech on these poorly drained soils, due to prolonged periods of poor aeration. Because of conditions unfavorable to the growth of beech, other species which are more tolerant to these conditions of poor aeration and which would have a more extensive root system, would grow better in this soil type. Beech trees on the better drained sites, however, would have better soil aeration and a deeper root system; soil moisture would not become as limiting in a drought year, nor aeration as limiting in an excessively wet year. Beech therefore reaches its best development on these better drained soils.

The roots of the less shade-tolerant swamp forest species, such as soft maple, white ash, and American elm, evidently can better withstand the periods of poor aeration occurring in the Marengo soil; therefore, they are the dominants in these poorly drained sites in which beech does not grow well. Sugar maple, the major competitor of beech, is probably even more adversely affected than beech by the poor aeration in the spring; therefore, it occurs as a dominant only on the better drained soil, such as the Cardington, in this forest. This shade-tolerant competitor reduces the area available to beech and causes it to decrease in importance in this better drained soil.

As can be seen from figure 1, both the total number of all tree stems and total basal area decrease with better drainage, especially from the Bennington to the Cardington soil. Lutz (1932) mentions the fact that the number of plant individuals decreases from poor to good sites and he attributes this to the more rapid growth and early expression of dominance of trees on better sites. However, such an explanation does not account for the decrease in basal area per unit area on the better drained sites of the study area. This reduction in both basal area and number more likely results from the lower available soil moisture and better aeration of the higher soils, which occurs consistently year after year. These conditions may allow individual trees to have large root systems and to grow to a large size, but they limit the number of individuals and total basal area that can occupy a given soil volume. In the Bennington, and more so along the margin of the Marengo, the supply of available soil moisture is frequently higher; thus, trees can grow in greater abundance per unit area. However, these trees on the less well-drained sites are more subject to climatic extremes and may be set back, if not killed, by exceedingly wet or dry years. It seems more likely that the occurrence of these extreme conditions prevents trees on the more poorly drained sites from reaching the large size obtained by those on the better drained soils.

Hence, it would appear that beech in central Ohio may have the most consistently favorable soil environment from year to year on the moderately well-drained Cardington silt loam because here it develops a deep root system. However, because of low available soil moisture and the presence of sugar maple, beech is not as abundant as it is on the imperfectly drained Bennington silt loam. In this less well-drained soil, sugar maple does poorly and soil moisture is frequently higher, allowing beech to become more abundant, although here it has a shallower root system. In the poorly drained outer border area of the Marengo silty clay loam, the beech reaches its lower limits. Here where soil moisture is often high, aeration is limiting and roots are restricted to the upper soil levels. When drought does occur, these shallow-rooted beech are most severly affected.

According to definitions of the several soil drainage classes given in the Soil Survey Manual, each class refers to, among other properties, the frequency and duration of periods of saturation in the various parts of the soil profile. For example, the Cardington silt loam is classed as being moderately well-drained, and according to this classification, the water is removed from the soil somewhat slowly, and the profile is wet for small but significant periods of time. The Bennington silt loam is classed as being imperfectly, or somewhat poorly, drained. Here the water, by definition, should be removed from the soil slowly enough to keep it wet for significant periods, but not all of the time. The Marengo is described as being very poorly drained, and here the water, by definition, should be removed from this soil so slowly that a water-saturated condition persists at or on the surface the greater part of the time. In the site investigated, however, the soil moisture units were along the border where the soil could be characterized as poorly drained, rather than very poorly drained, and thus water may have decreased somewhat more rapidly than is indicated by this last definition.

The soil moisture measurements charted in figure 8 provide some quantitative information on the actual drainage status in these three soils. In the moderately well-drained soil (Cardington), the soil moisture at six in. rarely remained at one-third atm for very long, even in May. However, internal drainage was impeded by the high clay content of the B, and in the upper horizons, saturation occurred for more extended periods in May and June. The lower B horizon at 24 in. remained saturated through June.

The imperfectly drained soil (Bennington) had a longer period in the spring when the upper layers were saturated as they received moisture from the slopes above. By late June or early July, conditions of soil moisture less than one-third atm were more common. The interesting thing noted here is that while the moisture at six in. remained high, the moisture at a 12-in. depth, where mottling is common, appears to have decreased more rapidly, even exceeding the moisture decrease at the same level in the better drained Cardington. This is probably the result of the high root density in this layer of the Bennington, which evidently counteracts the potentially more moist character of this soil. The most marked decrease in soil moisture at 24 in. did not occur until August, probably after roots had penetrated to this lower level.

The moisture in the poorly to very poorly drained Marengo soil was at or near field capacity (one-third atm), until it began drying out at the six in. level in July. This decrease in moisture through August appears to have been less rapid than in the soils at the higher sites, but by September it approached wilting percent level throughout the profile.

The observations made at these sites indicate some differences in the moisture status of the three soils; but, at least during the growing season, these differences are not as great as might be inferred from the definitions given in the Soil Survey Manual.

## SUMMARY

1. A comparison of the soil environment is made, grading from a very poorly drained site, where beech is at its lower limits in a swamp forest association, to a moderately well-drained site dominated by a beech-maple association. Three soil types occur over this transition: Marengo silty clay loam in the depression, Bennington silt loam on the gentle lower slopes, and Cardington silt loam on the better drained low ridges and knolls.

2. On the Marengo, beech is represented by a low basal area, as it is only an occasional associate of the swamp forest community; on the Bennington, beech reaches its greatest basal area and is the only major shade-tolerant competitor; but on the Cardington, the basal area of beech is somewhat less and sugar maple becomes more important. Both the total basal area of all trees and the total number per 1,000 $ft^2$ decrease only slightly from the Marengo to the Bennington soil, and then decrease more markedly from the Bennington to the better drained Cardington silt loam.

3. The soil profile characteristics, chemical and physical properties, relative root density, and temperature and moisture regimes are described for each soil type, and related to the development of the three forest communities.

a) The small basal area of beech on the Marengo silty clay loam of the depressions is attributed largely to high early-season soil moisture and low porosity, which contribute to poor aeration of the soil, allowing development of only a shallow and small beech root system. During either a drought or an excessively wet year, these shallow-rooted beech are affected more adversely than other swamp forest species. As a result, the less shade-tolerant but deeper rooted swamp forest species are more abundant.

b) On the imperfectly drained Bennington silt loam, better aeration capacity and shorter periods of water saturation are largely responsible for a more extensive root system in beech, which penetrates into, but not generally beyond, the high and compact clay B horizon. Here beech is not so severely affected by extreme weather conditions. On this site it is better able to compete with the less shade-tolerant swamp forest species, and becomes better developed than on the other soils of the study area.

c) On the moderately well drained Cardington silt loam, the finer structure, greater porosity, and well drained conditions lead to relatively high aeration at greater depths and beech develops a still deeper root system which extends even below the high clay B horizon and increases slightly in density and size in the C layer. With more runoff and shorter periods of high soil moisture, wet seasons are not as limiting. With the deeper and larger root system, beech can better withstand drought, even though soil moisture may be lower than in the Marengo soil. The smaller total basal area and number of all trees on this well drained Cardington soil is thought to be a result of lower available soil moisture. Since sugar maple also does well on this better aerated site, it is a major competitor and further reduces the area available to beech.

4. It appears that during the two growing seasons studied, differences in moisture conditions were not as great as might be inferred from the standard definitions of the drainage classes for the three types. The soil moisture in the highly mottled $B_{1g}$ of the Bennington shows a more marked decline due to the presence of many roots than does the soil moisture at the same depth in the better drained Cardington silt loam.

ACKNOWLEDGMENTS

Grateful acknowledgment is made to Dr. John N. Wolfe for his counseling and help in preparing this manuscript, to the Columbus Metropolitan Park Board for its cooperation, and to The Ohio Academy of Science for its grant to the project.

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